

# LONGHORN ARMY AMMUNITION PLANT

MARSHALL, TEXAS

AD 664122

## *Special Safety Study*

# TESTING "Nomex" MATERIAL AS HEAT RESISTANT CLOTHING FOR INDUSTRIAL APPLICATION

Report No. LD-17-67

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## THIOKOL CHEMICAL CORPORATION

CONTRACTOR—OPERATOR

CONTRACT DA-11-173-AMC-200(A)

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SPECIAL SAFETY STUDY .

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## ACKNOWLEDGEMENT

Thiokol Chemical Corporation, Operating Contractor of Longhorn Army Ammunition Plant, Marshall, Texas, would like to take this means of recognizing the cooperation and assistance of the members of the Textile Fibers Department of the E. I. DuPont de Nemours & Company, Inc., Willmington, Delaware, for their technical and material contribution to this series of tests.

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## INTRODUCTION

There are two requirements to be considered when selecting apparel for use in a hazardous thermal environment. The first is that the clothing itself shall not contribute to the wearer's injury by burning, melting, or disintegrating in the presence of a high energy heat source. The second is that the clothing system act as a thermal barrier which will effectively protect the wearer for a given interval of time.

As a part of the continuing effort at Thokol Chemical Corporation's Longhorn Division to give employees the best personal protection possible during the manufacture of "high energy heat source" munitions and rocket motors, a decision was made to test "Nomex" as a replacement for "flameproofed" cotton presently used as clothing material.

"Nomex" is a member of the "Nylon" family of fibers and was developed by E. I. DuPont de Nemours & Company, Inc. for applications requiring good dimensional stability and excellent heat resistance; the same basic requirements as stated above for use in a hazardous thermal environment.

"Nomex" has already been adopted by several military and civilian users for special applications, e.g., summer flying suits, the astronauts' uniform, U.S. Forestry Service uniform for fire fighters, etc.

See Appendix A, General Information & Data, for additional "Nomex" familiarization.

## DISCUSSION

The objective of this series of test was to determine the best combination of protective clothing (utilizing "Nomex" material) that would afford the line worker optimum protection against incident conditions. The data was recorded and developed for a period of time up to fourteen seconds. The first three to five seconds, however, are the most critical.

### TEST PREPARATION

#### Materials

A mannequin, test clothing, gloves, face shield, a flare pellet coated with Ignition Composition, thermocouples, lead wire, glass tape, oscillograph, photographic equipment, and two electric squibs for each test.

#### Clothing Combinations

The different combinations of clothing used in these test series are as follows:

<u>Test Number</u>	<u>Clothing</u>
1.	Seven ounce "Nomex" coveralls with no underclothing.
2.	Five ounce "Nomex" coveralls over four and three-tenths ounce "Nomex" underwear.
3.	Five ounce "Nomex" coveralls over seven ounce "Nomex" underwear.
4.	Seven ounce "Nomex" coveralls over four and three-tenths ounce "Nomex" underwear.
5.	Five ounce "Nomex" coveralls over "flameproofed" cotton coveralls.
6.	"Flameproofed" cotton coveralls over seven ounce "Nomex" underwear.
7.	Aluminized knee-length fiberglass coat over "flameproofed" cotton coveralls.
8.	"Flameproofed" cotton coveralls over cotton "T" shirt.

### Instrumentation

Instrumentation consisted of ten iron-constantan and two copper plate/iron-constantan thermocouples located on the surface of the mannequin in designated locations (see Fig. 11). These locations remained fixed for each test so that a comparison of the degree of protection afforded in each test could be accomplished.

Thermocouples were located in the following positions on the mannequin:

<u>Thermocouple</u>	<u>Location</u>
1	Palm of right hand
2	Inside of right wrist
3	Front of right bicept
4	Right chest
5	Right side
6	Right thigh
8	Right chest - between inner and outer garments
9	Right chest outside of garments
10	Right temple
11	Right chest (copper plate/iron-constantan)
12	Right thigh (copper plate/iron-constantan)

### TEST METHOD

#### Procedure

1. Attach thermocouples to mannequin in the designated locations. (Fig. 10)
2. Clothe mannequin for test and place in position with aluminum plate (to divert pellet when dropped) to simulate escape of person from presence of heat source. (Fig. 11)
3. Connect thermocouple leads.

4. Attach pellet to palm of right hand with glass tape.
5. Attach shunted squibs to pellet and extend lead wires down toward right leg.
6. Check to verify that the instrumentation and camera are ready and firing circuit is open.
7. Make final connection of firing circuit and lead wires.
8. Ignite pellet.

#### Performance

A review of the film taken during each test revealed that when ignited, the pellet developed a fire ball approximately three feet in diameter. The glass tape used to secure the pellet to the hand retained the pellet for an average of 600 milliseconds. This would closely approximate the reaction time of an individual in a similar situation. The pellet dropped to the aluminum plate propped against the mannequin's leg and rolled away from the mannequin.

#### Evaluation

Heat transfer is measured in the units of calories per second over a given area (per square centimeter) and is referred to as heat flux. The heat flux which can be tolerated by human tissue has been studied by a number of researchers<sup>1</sup> and a typical curve of heat flux versus time to produce pain and blister is shown on Figs. 1 and 2. These curves, developed by the Navy, indicate the time to produce pain or second degree burn at various levels of heat flux. A high level of heat flux can be tolerated for only a very short time whereas considerably longer times may be tolerated with low levels of heat flux.

A copper plate/iron-constantan thermocouple and oscillograph was used to register and record the amount of exposure during the test. The temperature rise per second (°F) was calculated and plotted (Fig. 1) to determine the heat flux. The heat flux was then plotted on a heat flux versus time to pain and blister curve (Fig. 2) at one second intervals of exposure to determine the potential for tissue damage.

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<sup>1</sup> Stoll, Alice M. and Greene, Leon C. "Relationship Between Pain and Tissue Damage Due to Thermal Radiation", Journal of Applied Physiology, 1959, 14(3):373-382

Buettner, Konrad, Ph. D., "Effects of Extreme Heat on Man, Protection of Man Against Conflagration Heat", Journal of American Medical Association, October 28, 1950, pp 732-738.



## TEST RESULTS

Test 1 - This test was conducted as a feasibility test only and was not considered in the final analysis as suitable attire since the mannequin was dressed only in the seven ounce "Nomex" coveralls.

Test 2 - An examination of the mannequin after the test revealed that the five ounce "Nomex" coveralls developed a hole extending from under the arm pit and shoulder seam to about the middle of the thigh and charred from the middle of the thigh to the knee. (Fig. 12 is typical of the pattern burned in five ounce coveralls.) The hole extended from the buttons in the center of the chest to a line under the right arm pit.

The "Nomex" underclothing under the coveralls had three badly scorched areas, one area approximately two inches in diameter on the chest and two on the right hip about the same size.

The heat flux vs. time to pain and blister threshold curve for this test (Fig. 3), indicates heat flux sufficient to cause pain and probably first degree burns.

Test 3 - The five ounce "Nomex" coveralls used in this test opened up identically to those used in Test 2. However, the seven ounce "Nomex" underclothing beneath the coveralls showed only light scorch marks on the outside of the material; these being in the area of the right chest and hip.

The heat flux vs. time to pain and blister threshold for this test (Fig. 4), indicates that the heat flux did not approach the pain threshold.

Test 4 - The inspection following this test revealed that the seven ounce "Nomex" coveralls developed a hole in the area of the right chest approximately 5 x 9 inches in size. A charred area extended from the waist to the knee. (Fig. 13 is typical of the pattern burned in seven ounce "Nomex" coveralls.)

The heat flux vs. time to pain and blister threshold curve for this test (Fig. 5), indicates no approach to the pain threshold and consequently a burn would not have resulted.

Test 5 - The five ounce "Nomex" coveralls used in this test developed a hole identical to those developed in Tests 2 and 3, i. e. from the arm pit to the middle of the thigh and from the buttons in the center of the chest to a point in line with the arm pit (Fig. 12). The flameproof coveralls beneath the "Nomex" coveralls charred in the area of the right chest. The charred area was 11" long and 3" wide and was centered between the shoulder and the waist.

The heat flux vs. time to pain and blister threshold curve for this test (Fig. 6), shows an initial increase and decrease in the heat flux as the pellet is ignited and drops away. However, at 2.5 seconds, the flameproof cotton continues to smolder causing the heat flux to rise again. Although the coveralls continued to burn for several seconds, the heat flux did not approach the pain threshold.

Test 6 - During this test, the flameproof cotton coveralls flamed up and burned extensively on the right side and leg (Fig. 15). Although the seven ounce "Nomex" underwear protected the mannequin for approximately nine seconds, it finally charred through and the heat flux increased to a point beyond the pain threshold. This is shown on the heat flux vs. time to pain and blister curve for this test on Fig. 7.

Test 7 - An inspection of the aluminized coat after this test revealed the coat to be blackened in the area of the right chest. The aluminized coating over the fiberglass appeared to have remained intact with the exception of a one inch strip across the right chest. (This is not visible in Fig. 17) At this point, the threads of fiberglass were visible; however, the underside of the garment remained intact.

The heat flux vs. time to pain and blister curve for this test (Fig. 8) shows the aluminized coat to be very satisfactory since the heat flux remained at a low value.

Test 8 - The flame proof cotton coveralls burned quite extensively in this test. They continued to smolder until extinguished as indicated on the heat flux vs. time to pain and blister curve (Fig. 9); the heat flux extends beyond the blister threshold.

A comparison of the temperatures recorded for each test at each thermocouple location is listed as Appendix B.

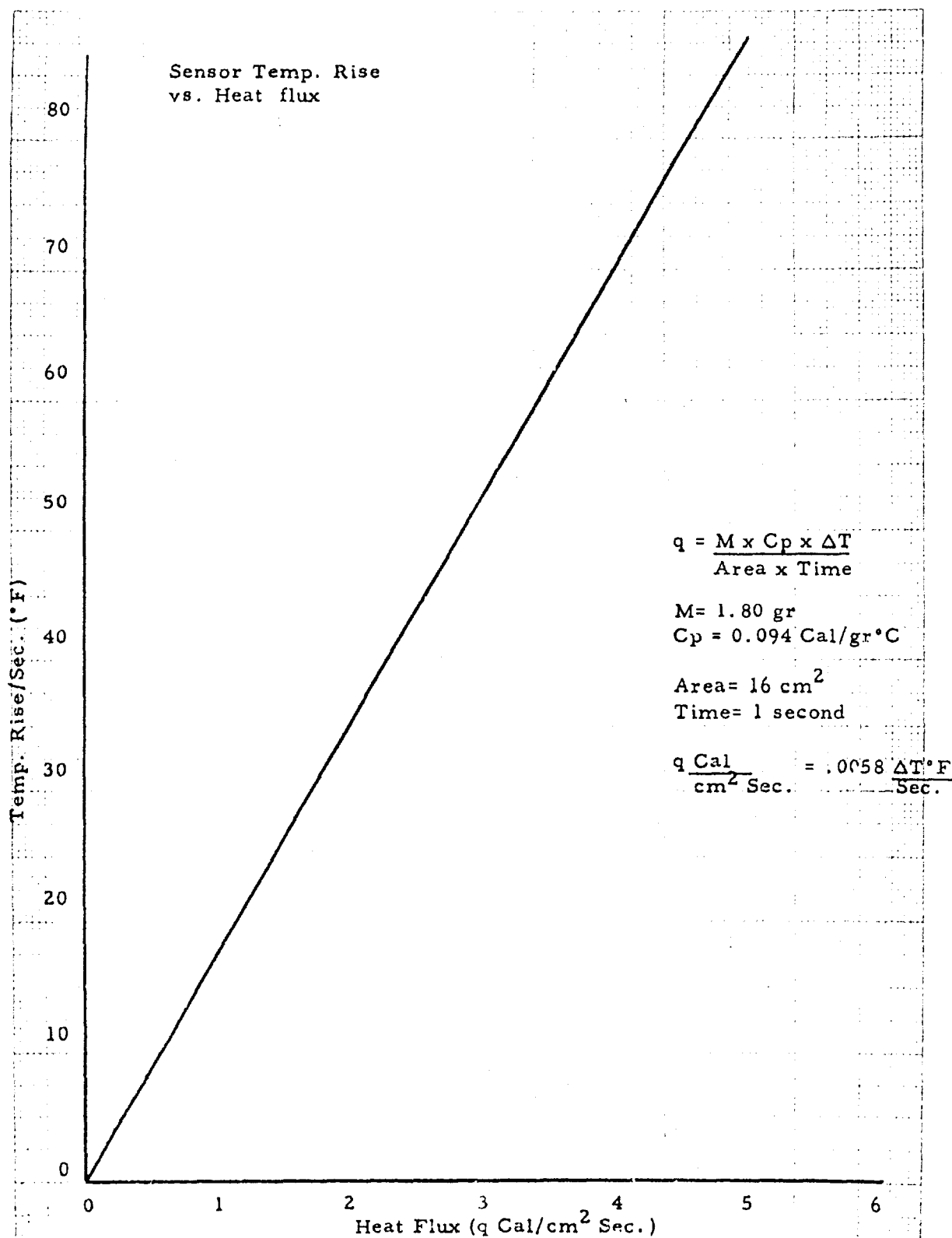
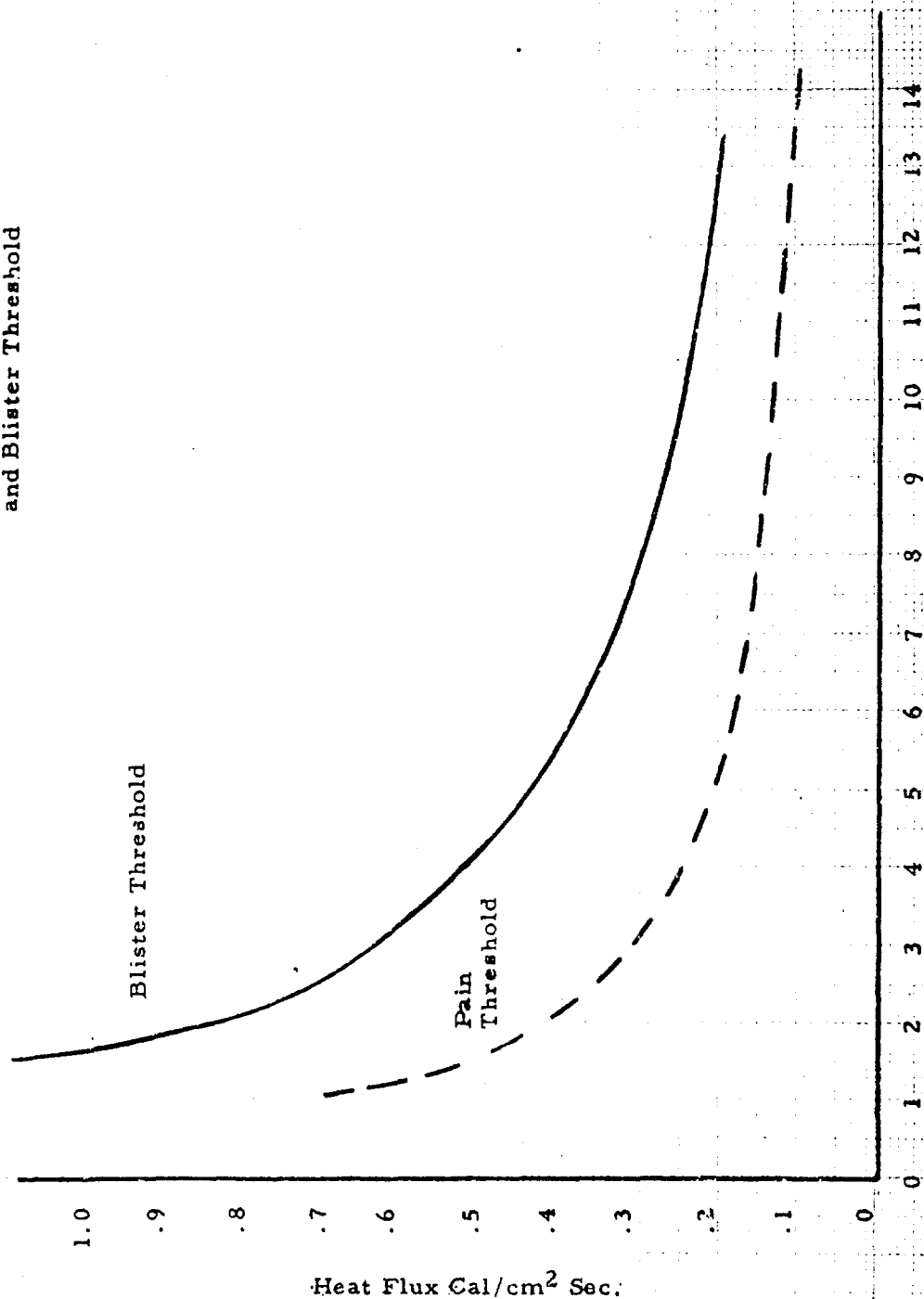


Figure 1

# Heat Flux vs Time to Pain and Blister Threshold



Time (Sec.)

Figure 2

# Heat Flux vs. Time to Pain and Blister Threshold

5 oz. "Nomex" Coverall  
Over Light Weight Under-  
wear of "Nomex" Test No. 2

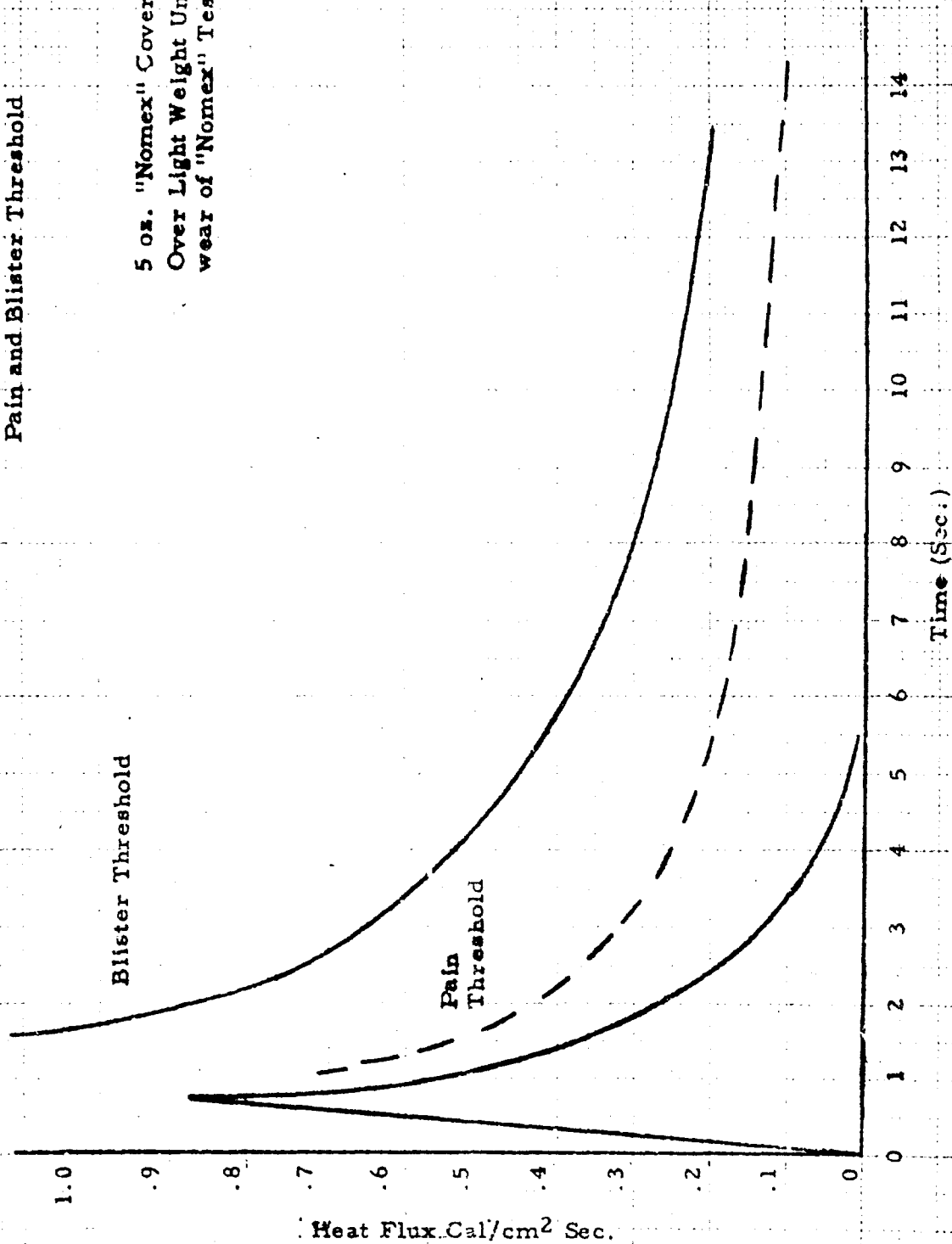


Figure 3

# Heat Flux vs. Time to Pain and Blister Threshold

5 oz. "Nomex" Coverall over  
Sears "Nomex" Thermal

Test No. 3

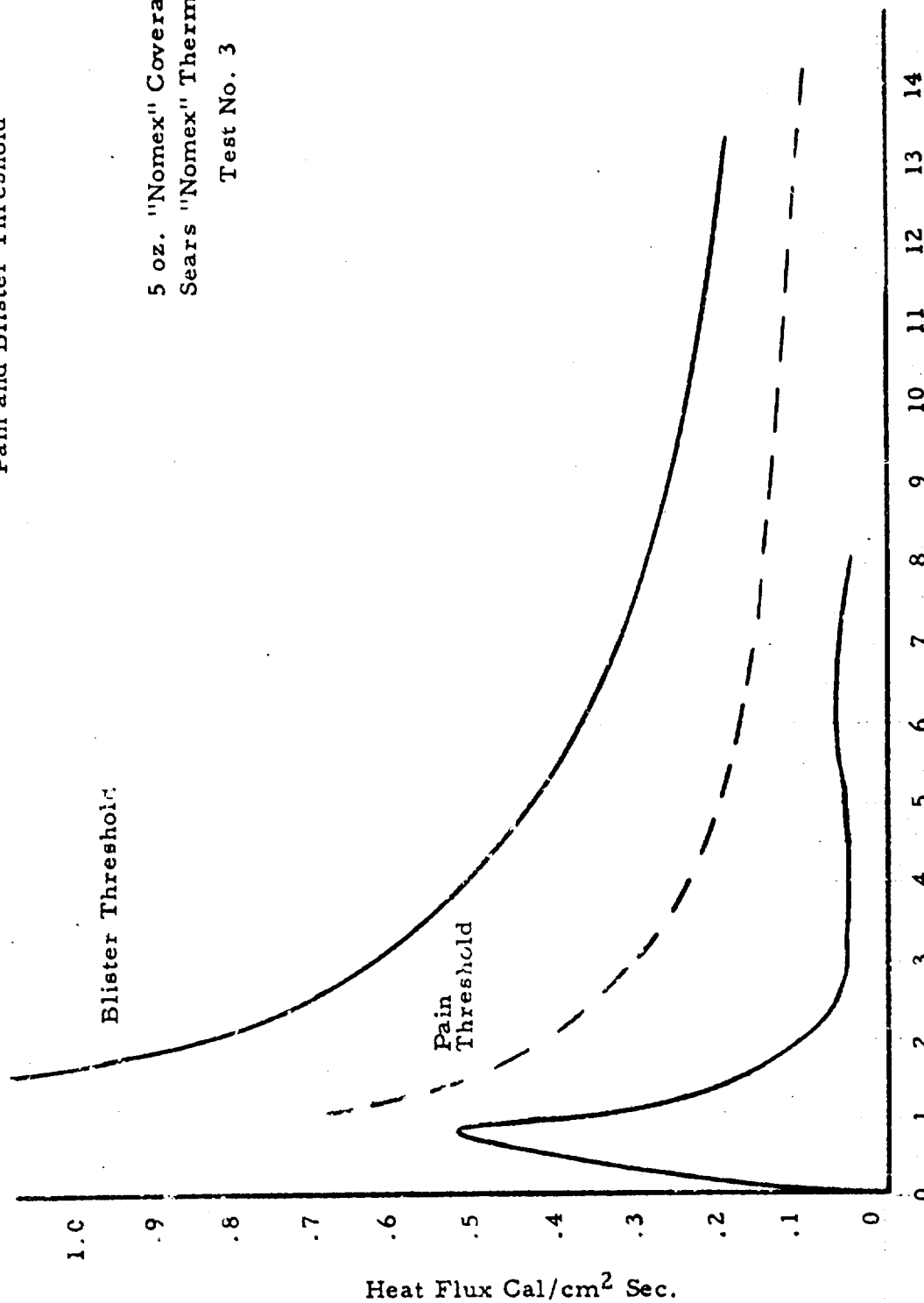


Figure 4

# Heat Flux vs. Time to Pain and Blister Threshold

7 oz. "Nomex" Coverall over  
Light Weight "Nomex" Underwear

Test No. 4

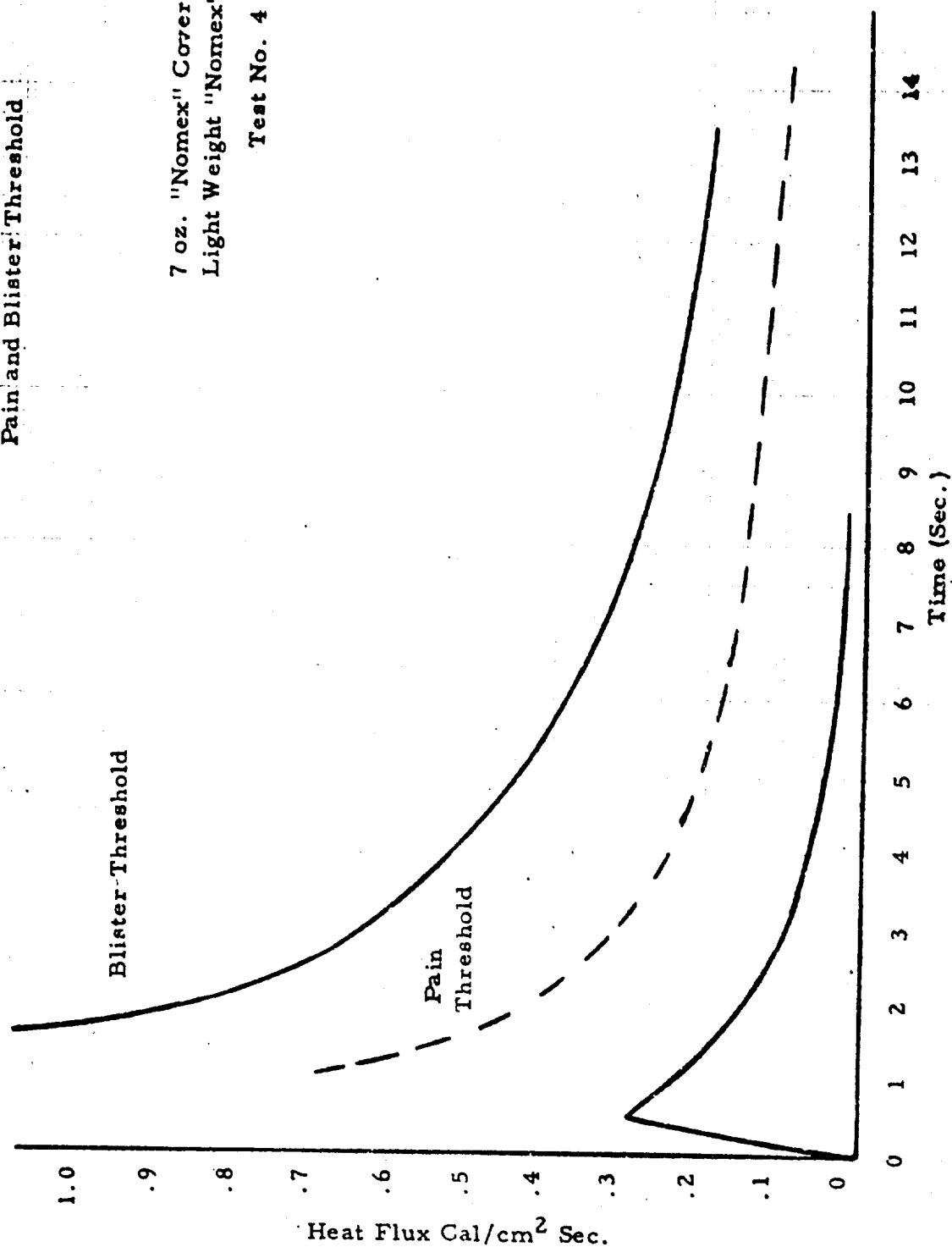


Figure 5

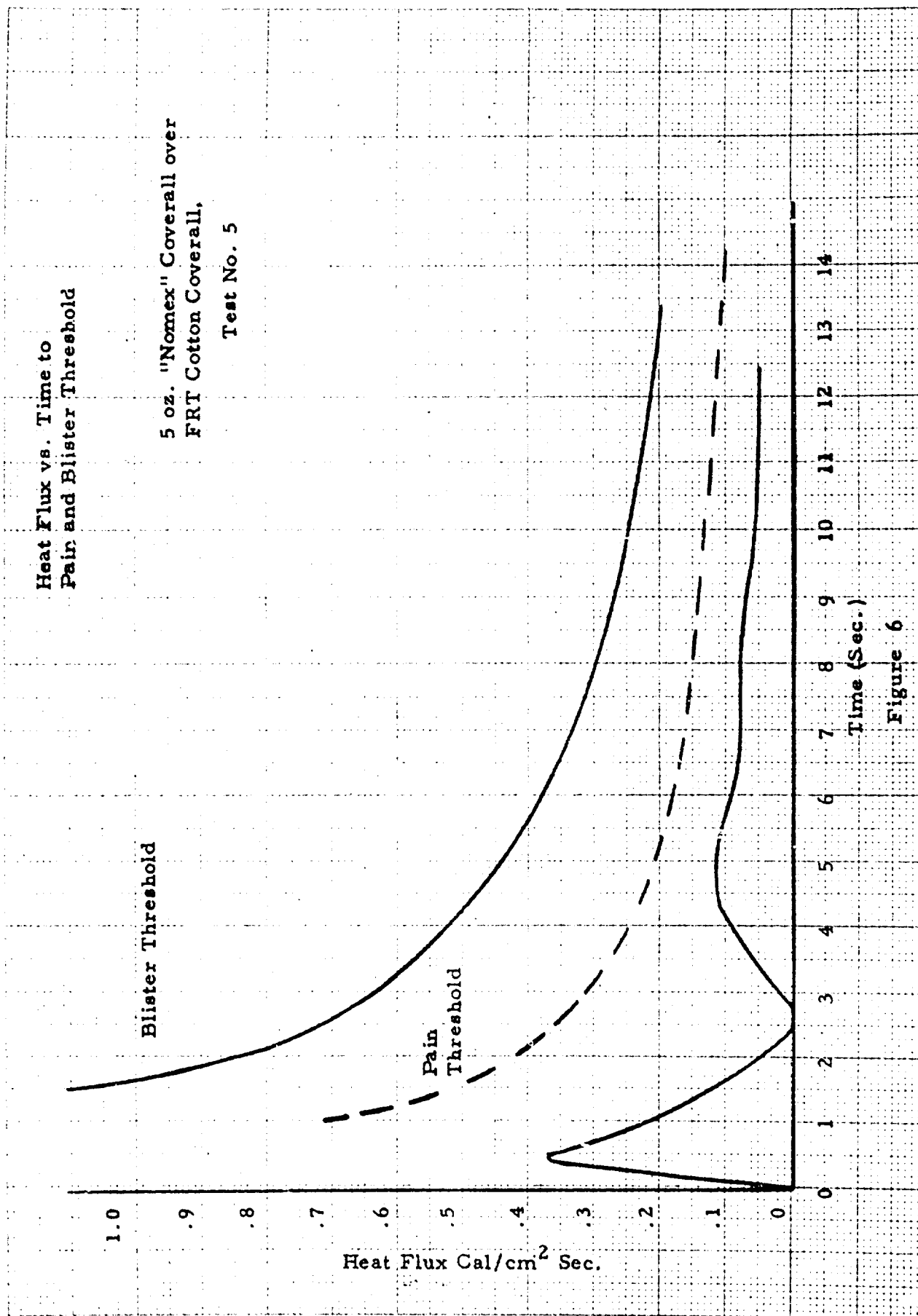


Figure 6



Heat Flux vs. Time to  
Pain and Blister Threshold

FRT Coveralls over  
Sears Thermal Knit "Nomex"  
Test No. 6

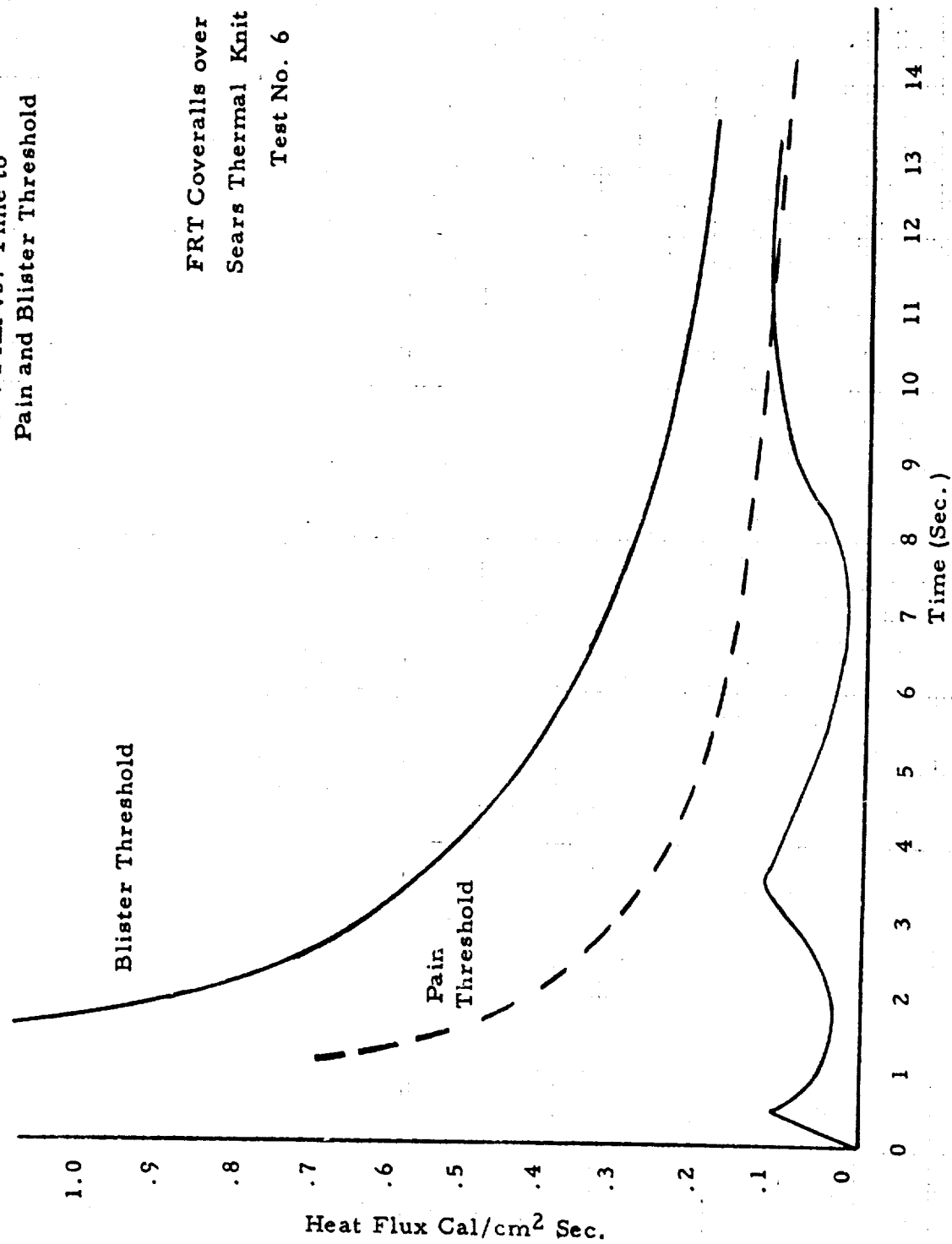


Figure 7

# Heat Flux vs. Time to Pain and Blister Threshold

Aluminized Coat over  
FRT Cotton

Test No. 7

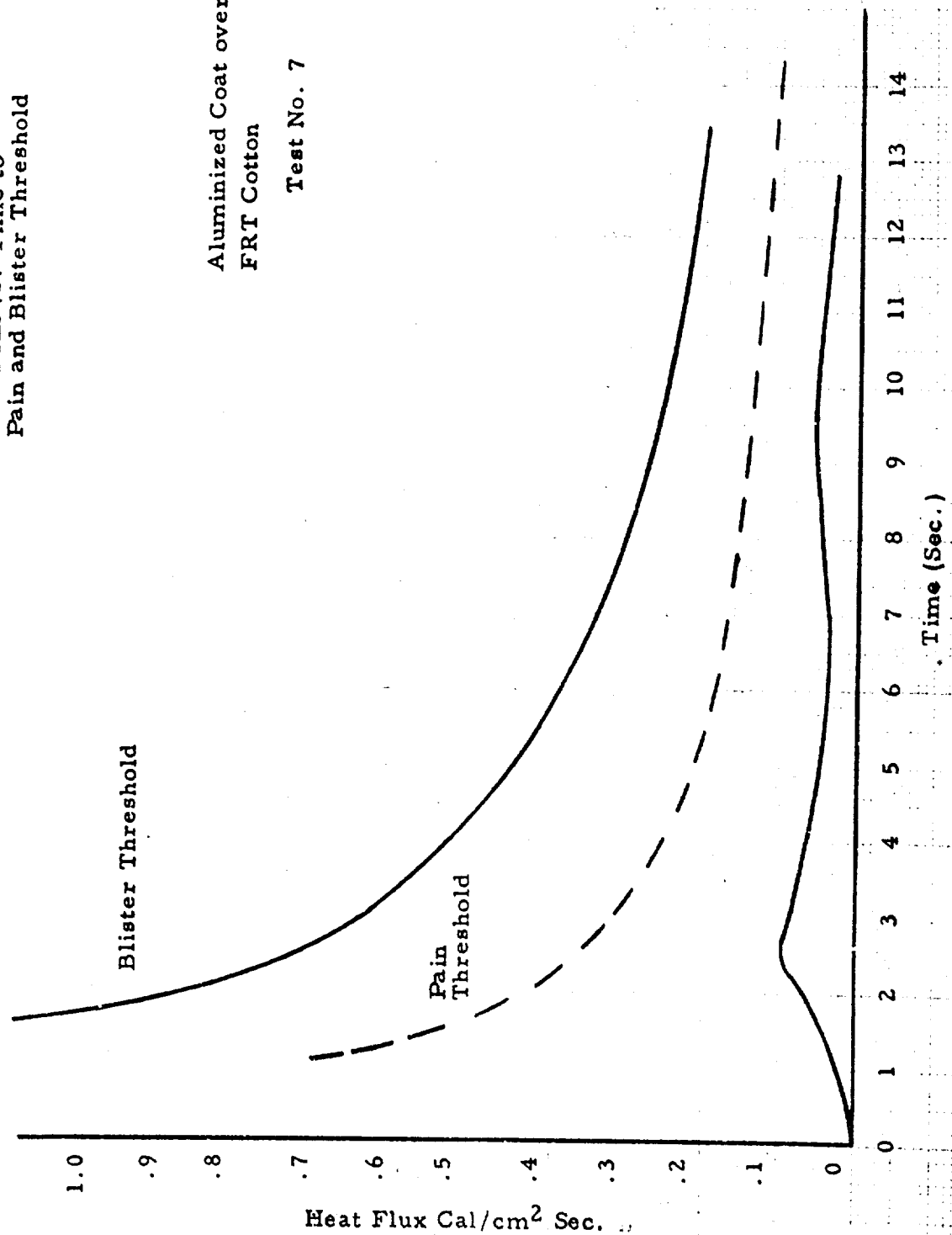


Figure 8

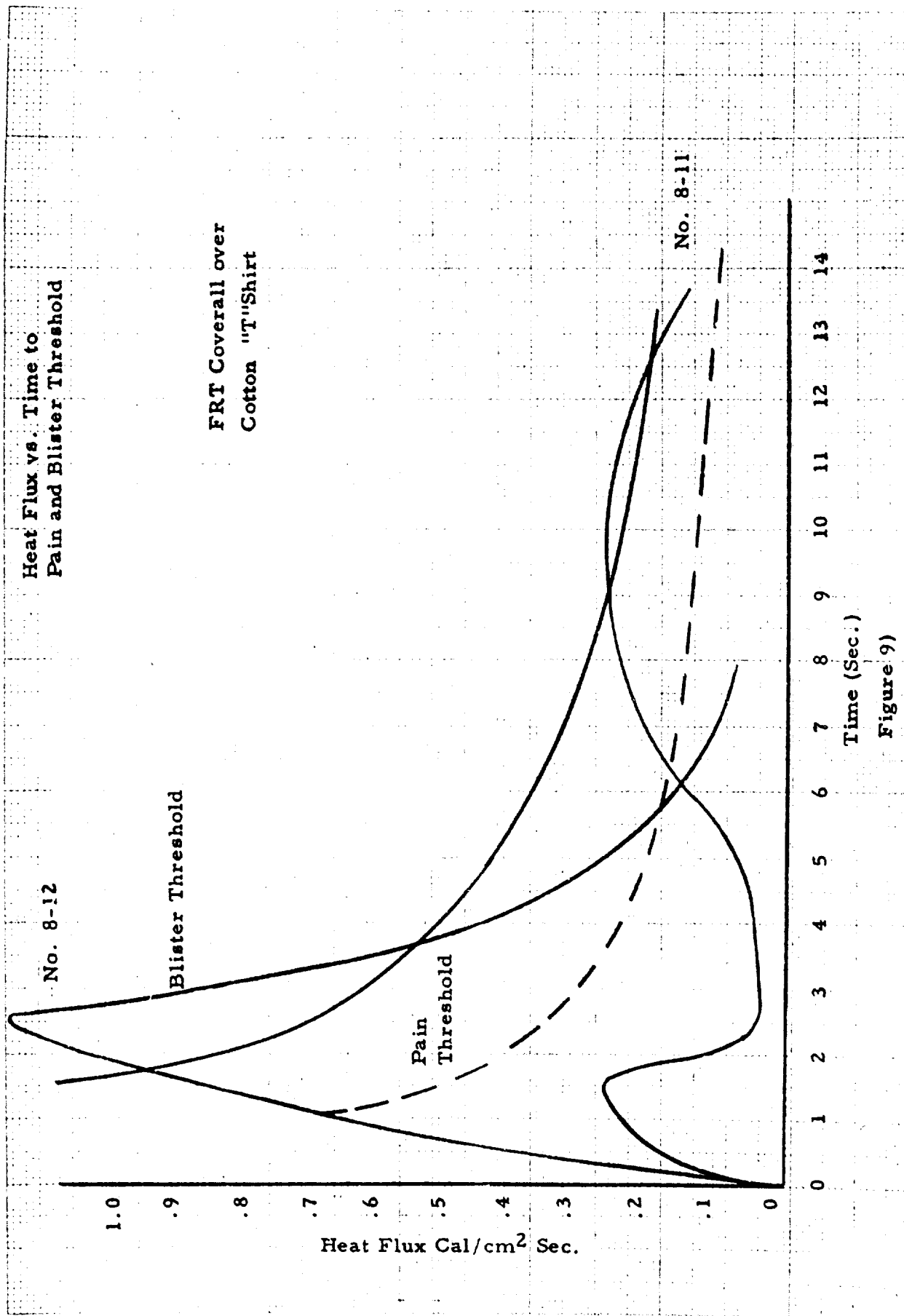




Fig. 10

MANNEQUIN SHOWING  
THERMOCOUPLES IN  
POSITION

Fig. 11

TYPICAL TEST SET-UP  
(Test No. 2 - See Fig. 12  
for Results)





Fig. 12

TEST RESULTS  
TEST NO. 2  
(Typical Results of  
5-ounce "Nomex"  
Coveralls)

Fig. 13

TEST RESULTS  
TEST NO. 4  
(Typical Results of  
7-ounce "Nomex"  
Coveralls)





Fig. 14

TYPICAL TEST SET-UP  
(Test No. 6)

Fig. 15

RESULTS OF TEST NO. 6





Fig. 16  
TEST SET-UP  
(Test No. 7)

Fig. 17  
TEST RESULTS  
(Test No. 7)



## CONCLUSIONS

The heat flux versus time to pain and blister threshold curves (Figs. 3-9) indicate that clothing combinations worn in Tests 3, 4, and 7 should protect a person from burn when exposed to a source of heat similar to that used in the test. Clothing combinations worn in Tests 2, 6, and 8 would not be satisfactory in the presence of a high energy heat source since burns would likely occur. The clothing worn in Test 5 indicates protection in this test; however, there is a possibility that the flameproof cotton coveralls could burn more severely in additional testing. This combination (Test 5) would be considered a marginal system without additional testing to verify the results. (Note: Test 1 was conducted as a feasibility test only).

Although the aluminized fiberglass clothing has shown in this test series and in actual experience that it will protect the worker best, it has two distinct disadvantages. First, the coat is very uncomfortable to wear, especially in warm weather; second, it does not possess the resistance to chemicals that "Nomex" possesses. Table I, Appendix A, shows that after 1,000 hours of exposure to acetone, Freon 113, or alcohol, there was little or no effect on the breaking strength of the "Nomex" material.

The clothing combination worn in Test 4 appears to offer optimum protection for an industrial application such as Longhorn Army Ammunition Plant. This combination consists of the seven ounce "Nomex" coveralls and four and three-tenths ounce short sleeve and short leg underwear. This combination indicates a greater degree of protection than the five ounce "Nomex" coveralls over the seven ounce full length "Nomex" underwear as worn in Test 3, but did not protect as well as the bulky aluminized clothing as demonstrated in Test 7.

The ability of "Nomex" to protect is based to a large extent on the outer layer of material charring and trapping air between the outer and inner layers of cloth. (Fig. 13 - below the waist)

"Nomex" will be phased into use at Longhorn. Due to the problems associated with issuing two types of underclothing, it has been decided to use cotton underclothing with six ounce "Nomex" coveralls and six ounce "Nomex" laboratory type coats in the most hazardous locations. This combination, although not included in this series of tests, will provide protection equal to or better than the seven ounce coveralls over the four and three-tenths ounce underwear. With this combination, it will be easily ascertained that a person is properly clothed, and secondly, the laboratory coat will afford more coverage of the body than the short sleeve and short leg underwear.



## APPENDIX A

"NOMEX" INFORMATION & DATA  
CHEMICAL RESISTANCE OF "NOMEX"  
INDUSTRIAL WEAR TEST

## APPENDIX A

### NOMEX INFORMATION AND DATA

#### Static Electricity

Many synthetic fabrics and some blends are subject to static electricity in low humidity atmospheres. There is no known permanent anti-static treatment; however, there are anti-static treatments which can be re-applied on washing and will control static electricity. To control static electricity, it is suggested that an antistat be applied in the final rinse water after the garments are washed. The following data indicates the degree of control possible with such an antistat:

	<u>Electrical Resistivity in 10<sup>8</sup> OHMS at 25% R. H.</u>
Fabrics of "Nomex", no anti-static treatment	93,000
100% cotton, no anti-static treatment	30,000
Fabrics of "Nomex" treated with an antistat	9,800

Some of the suitable antistats are:

"Ethoquad" 0/12  
"Ethoquad" C/12  
Armour Ind. Chemical Company  
Chicago, Illinois

"Palostat"  
DuPaul Chemical Company  
Long Island, New York

"TLF" 1207  
E. I. Du Pont de Nemours and Company  
Wilmington, Delaware

#### Washing Procedure for Clothing of "Nomex"

Normal plant laundry procedures are satisfactory for "Nomex" with one exception: DO NOT ADD BLEACH! Normal detergents should be used as

long as they do not contain bleach.

A treatment for static should be added in the final rinse water. Antistat in the amount of 2% of the dry garment weight, be added for 40% relative humidity and above 4% for 20 to 40% relative humidity.

#### Availability

Although Du Pont is currently manufacturing "Nomex" fiber on a pilot line, they are producing a sufficient quantity to keep textile plants supplied. A production plant for manufacture of the "Nomex" fiber will be "on stream" this year. The only colors available are off-white and green. Other colors are currently being developed and will be available in 1968.

#### Cost

The initial cost of "Nomex" is quite high compared to cotton. Quotations received from various manufacturers bidding on the manufacture of 700 pair of six ounce men and women's coveralls ranged from \$27 to \$40. Although the initial cost is high in comparison to cotton, industrial wear tests show that there is an economic incentive to buy the "Nomex". (See Industrial Wear Tests, this appendix).

Since a powder suit is very simple to make, the cost, which is mostly the cost of the "Nomex" material, should drop once the "Nomex" fiber production plant is in operation.

**TABLE I**  
**CHEMICAL RESISTANCE OF "NOMEX"**  
**HIGH TEMPERATURE RESISTANT NYLON<sup>1</sup>**

Chemical	Concentration / Temperature      Time				Effect On Breaking Strength+				
	(%)	(°F)	(°C)	(Hrs.)	None	Slight	Moderate	Appreci- able	De- graded
<b>Strong, Mineral Acids</b>									
Hydrochloric	10	203	95	8				X	
Hydrochloric	35	70	21	10	X				
Hydrochloric	35	70	21	100				X	
Nitric	10	70	21	100	X				
Nitric	70	70	21	100				X	
Sulfuric	10	70	21	100	X				
Sulfuric	10	140	60	1,000			X		
Sulfuric	60	140	60	100			X		
Sulfuric	70	70	21	100		X			
Sulfuric	70	203	95	8				X	
<b>Organic Acids</b>									
Acetic	100	70	21	1,000	X				
Acetic	100	200	93	10	X				
Benzenesulfonic	100	200	93	10				X	
Benzoic	sat. sol.	200	93	10	X				
Formic	91	70	21	1,000	X				
Formic	91	200	93	10		X			
Lactic	75	70	21	1,000	X				
Oxalic	10	200	93	10		X			
Oxalic	sat. sol.	70	21	1,000		X			
Trifluoroacetic	100	70	21	1,000		X			
<b>Strong Alkalis</b>									
Amm. hydroxide	28	70	21	100	X				
Sodium hydroxide	10	70	21	100	X				
Sodium hydroxide	10	140	60	100		X			
Sodium hydroxide	10	203	95	8				X	
Sodium hydroxide	40	70	21	10	X				
Sodium hydroxide	50	140	60	100					X
<b>Bleaching Agents</b>									
Peracetic acid	100	70	21	10	X				
Sodium chlorite	0.5	70	21	10	X				
Sodium chlorite	0.5	140	60	100			X		
Sodium hypochlorite	0.4	70	21	10	X				

<sup>1</sup>Extracted from "Properties of Nomex" Technical Information Bulletin N-201, Textile Fibers Department, Industrial Marketing Division, E. I. DuPont de Nemours & Co. Inc.

Chemical	Concentration/ Temperature				Time (Hrs.)	Effect On Breaking Strength+				
	(%)	(°F)	(°C)	None		Slight	Moderate	Appreci-	De-	
								able	graded	
<u>Organic Chemicals</u>										
Acetone	100	70	21	1,000	X					
Acetone	100	133	**56	10	X					
Benzene	100	70	21	1,000	X					
Benzene	100	176	**80	10	X					
Carbon disulfide	100	70	21	1,000	X					
Carbon tetrachloride	100	70	21	1,000	X					
Carbon tetrachloride	100	171	**77	10	X					
Cresol (meta-)	100	70	21	1,000	X					
Cresol (meta-)	100	395	**202	10	X					
Dimethyl- acetamide	100	70	21	1,000		X				
acetamide	100	200	93	10	X					
formamide	100	158	70	168	X					
formamide	100	307	**153	10	X					
sulfoxide	100	70	21	1,000		X				
sulfoxide	100	200	93	10			X			
Ethyl alcohol	100	70	21	1,000	X					
Ethylene glycol	100	70	21	1,000	X					
Ethylene glycol	100	158	70	168	X					
Ethylene glycol	100	200	93	10	X					
Formaldehyde	10	70	21	1,000	X					
Freon-113*refrig.	100	70	21	1,000	X					
Gasoline(lead)	100	70	21	1,000	X					
Jet fuel	100	158	70	168	X					
Methyl alcohol	100	70	21	1,000	X					
Methyl alcohol	100	148	**65	10	X					
Nitrobenzene	100	70	21	1,000	X					
Nitrobenzene	100	200	93	10	X					
Perchloroethylene	100	158	70	168	X					
Phenol	10	70	21	1,000	X					
Phenol	100	200	93	10	X					
Stoddard solvent	100	70	21	1,000	X					
Xylene (meta-)	100	158	70	168	X					
<u>Sealed-Tube Exposures</u>										
Air+5%water+5% sulfur dioxide++	--	347	175	100					X	
Freon-22* refrig.	--	356	180	1,000	X					
Sulfur hexafluoride	--	356	180	1,000		X				
Steam saturated at 79 psia.	--	311	155	100				X		

\*Registered DuPont trademark

\*\*boiling point

++Percent by weight

+None = 0-9% loss

Slight = 10-24% loss

-25-

Moderate = 25-44% loss

Appreciable = 45-79% loss

Degraded = 80-100% loss

## INDUSTRIAL WEAR TEST

### Chambers Works - E. I. DuPont de Nemours & Company

In June of 1963 a small wear test was initiated with the Engineering Maintenance Group at this Plant. Twenty-one garments were distributed to representative groups and the test was started.

After 13 months, the test was terminated despite the fact that only one set of garments had been worn out (a special case where "Nomex" outlasted FRT cotton 15-1). The Plant Clothing Committee had obtained sufficient information to demonstrate the advantage of "Nomex" over flame retardant treated cotton to the extent that they recommended the purchase of 500 sets of garments for a final prove-out.

In this preliminary test only a few garments had run long enough to justify cost, although at the termination all garments were in excellent shape. It did show that they were comfortable, easily cleaned, dimensionally stable and durable. On this basis a 500-garment test was initiated in November of 1965.

Garments for the final prove-out were distributed--two sets/operator--on the following basis:

Engineering	140
Manufacturing	140
Chemicals	140
Stores and Transport	80

These garments are now in their 18th month of use. Since each suit is worn every third day, this represents nearly six month's wear per garment. All garments are in excellent shape and an additional six month's wear per garment is expected. FRT cotton garments average 1-3 month's wear life with the average being 2 months. Thus far "Nomex" has a 3x wear life and is expected to reach at least 6x.

### Niagara Falls - E. I. DuPont de Nemours & Company

Tests were initiated at this plant in September of 1965 and additional garments were supplied as indicated in following table. The table indicates the current status of the test. No garment failures have occurred and it is expected that they will reach 275 days (equivalent to one year's life).

<u>Date Issued</u>	<u>Trousers or Overalls</u>	<u>Shirts</u>	<u>Days Worn Average/ Garment</u>	<u>Launderings Average/ Garment</u>
9-13-65	4-T		226	45
9-27-65	1-T	1	236	47
12-15-65	13-T, 3-O	2	203	41
3-1-65	<u>23-T, 10-O</u>	<u>19</u>	171	34
	41-T, 13-O	22		

Records indicate that the cotton garments currently in use are replaced on the average every 15 wear days (based on average issue of 12 dungarees, 3 overalls and 11 shirts per employee per year).

On the basis of cost (cotton at \$4/set vs. "Nomex" at \$55/set), "Nomex" is already being justified on the basis of long life. It should also be noted that cotton garments are usually more expensive than \$4/set, however, the severe environment has made it desirable to use less expensive garments.

## **APPENDIX B**

**"NOMEX" TEST SERIES**

**THERMOCOUPLES # 1 THROUGH 12**



NOMEX TEST SERIES  
DEGREES - F  
THERMOCOUPLE NO. 1 - PALM OF RIGHT HAND

<u>Time (Seconds)</u>	<u>TEST NUMBER</u>							
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
0.0	+79°	+62°	+75°	+71°	+59°	+58°	+60°	+70°
0.5	112	63	86	253	89	70	195	124
1.0	128	63	122	212	107	83	294	186
1.5	139	63	141	240	112	92	357	212
2.0	150	63	148	264	117	94	392	228
2.5	155	64	149	281	119	122	412	233
3.0	166	65	150	296	121	145	424	238
3.5		66	147	303	121	152	434	243
4.0		68	145	316	120	152	440	248
4.5		70	144	324	117	151	444	253
5.0		71	144	329		150	448	264
5.5		74	144	335		148	451	269
6.0		75	144	339			450	274
6.5		77	144	343			448	279
7.0		80	144	346			445	279
7.5		80	145	350				284
8.0		83	145	353				284
8.5		84	147	356				284
9.0		86	148	359				284
9.5		88	148	363				284
10.0		89	149	365				284
10.5		89	149	365				279
11.0		90	150	366				279
11.5		92	151	366				279
12.0		92	152	366				
12.5		92	152	365				
13.0		93	153	365				
13.5		94	154					
14.0		94	155					

Material Over  
Thermocouple

A A A A A A B B

Legend:

- A. Nomex Gloves Woven Over Knit
- B. Edmont Standard

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES  
DEGREES - F  
THERMOCOUPLE NO. 2 - RIGHT WRIST

<u>Time (Seconds)</u>	<u>TEST NUMBER</u>							
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
0.0	+62°	+57°	+71°	+79°	+43°	+56°	+60°	+60°
0.5	63	57	73	93	128	62	70	76
1.0	63	58	73	130	127	67	102	108
1.5	63	58	74	143	123	67	125	165
2.0	63	58	75	151	123	67	137	186
2.5	64	58	77	156	122	69	144	191
3.0	65	58	78	160	119	73	148	196
3.5	66	59	78	163	117	73	149	207
4.0	68	60	79	168		72	151	207
4.5	70	61	80	176		71	152	217
5.0	71	62	81	183			153	222
5.5	74	63	82	191			153	227
6.0	75	63	82	199			153	232
6.5	77	63	83	207			153	243
7.0	80	64	84	214			153	248
7.5	80	64	85	221			154	258
8.0	83	64	86	225			156	263
8.5	84	64	87	231			156	273
9.0	86	64	87	237			156	288
9.5	88	64	88	241			157	288
10.0	89	65	89	245			157	313
10.5	89	65	89	249			158	323
11.0	90	65	90	252			159	333
11.5	92	66	90	255			159	349
12.0	92	66	91	257			160	369
12.5	92	66	91	260			161	384
13.0	93	66	91	261			161	398
13.5	94	67	91	264			161	408
14.0	94	67	92	264			162	413

Material Over  
Thermocouple

A B B B B B C D

Legend:

- A. Leather Gauntlet of Nomex Glove
- B. Nomex Gloves Woven Over Knit
- C. Aluminized Coat Sleeve
- D. Flameproof Cotton Coverall Sleeve

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES  
DEGREES - F  
THERMOCOUPLE NO. 3 - FRONT OF RIGHT BICEPT

	<u>TEST NUMBER</u>							
<u>Time (Seconds)</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
0.0	+91°	+77°	+75°	+76°	+58°	+65°	+63°	+71°
0.5	114	92	83	95	63	72	63	77
1.0	124	116	92	145	70	83	63	87
1.5	131	129	94	155	81	84	64	129
2.0	138	133	95	163	91	85	64	145
2.5	142	136	97	170	98	89	63	160
3.0	147	141	97	175	103	96	63	181
3.5		150	98	178	107	110	63	211
4.0		158	98	184	110	120	63	237
4.5		166	98	191	110	127	63	262
5.0		172	99	197	112	132	63	277
5.5		176	99	203	113	137	63	282
6.0		177	99	209	113	140	63	297
6.5		178	99	214	113	147		312
7.0		179	99	217	113	152		327
7.5		177	99	222	113	155		342
8.0		176	99	224	113	157		352
8.5		175	99	226	113	158		367
9.0		173	99	227	114	163		377
9.5		170	100	229	114	164		391
10.0		168	100	233	115	165		401
10.5		166	100	235	116	165		411
11.0		164	100	237	117	165		431
11.5		162	100	238	118	166		441
12.0		160	100	241	119	166		461
12.5		158	100	242	120	166		476
13.0		155	100	243	121	167		490
13.5		153	100	244	122	169		510
14.0		151	100	244	122	170		525

Material Over  
Thermocouple

Legend:

- A. 7 oz. Nomex Coveralls
- B. 5 oz. Nomex Coveralls over 4.3 oz. Nomex Short Sleeve & Short Leg Underwear
- C. 5 oz. Nomex Coveralls over 7 oz. Nomex Full Length Underwear
- D. 7 oz. Nomex Coveralls over 4.3 oz. Nomex Short Sleeve & Short Leg Underwear
- E. 5 oz. Nomex Coveralls over Flameproof Cotton Coveralls
- F. Flameproof Cotton Coveralls over 7 oz. Nomex Full Length Underwear
- G. Aluminized Coat over Flameproof Cotton Coveralls
- H. Flameproof Cotton Coveralls over Cotton "T" Shirt

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES  
DEGREES - F  
THERMOCOUPLE NO. 4 - RIGHT CHEST

	<u>TEST NUMBER</u>							
<u>Time(Seconds)</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
0.0	NO THERMOCOUPLE	+93°	+87°	+79°	+73°	+74°	+76°	+81°
0.5		104	102	93	79	80	76	86
1.0		157	138	130	90	81	76	91
1.5		165	153	143	109	81	80	108
2.0		176	159	151	125	82	89	124
2.5		187	163	156	136	83	102	134
3.0		194	169	160	142	83	113	140
3.5		198	177	163	145	84	121	150
4.0		201	184	168	146	84	127	150
4.5		203	190	176	148	85	133	155
5.0		205	195	183	150	65	137	155
5.5		205	200	191	153	85	141	160
6.0		205	204	199	158	86	144	160
6.5		205	208	207	164	86	148	166
7.0		205	210	214	171	87	152	166
7.5		202	213	221	177	88	156	171
8.0		202	215	225	184	89	161	171
8.5		201	217	231	191	90	165	176
9.0		199	219	237	197	90	170	181
9.5		197	220	241	204	91	174	186
10.0		195	221	245	210	91	178	192
10.5		193	222	249	215	92	181	192
11.0		191	224	252	221	92	185	197
11.5		188	224	255	226	93	187	197
12.0		185	225	257	233	94	191	202
12.5		183	225	260	238	94	193	202
13.0		180	225	261	243	95	195	207
13.5		178	226	264	248	96	196	207
14.0		175	225	264	252	96	198	207

Material Over  
Thermocouple

A      B      C      D      E      F      G

Legend:

- A. 5 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
- B. 5 oz. Nomex Coveralls over 7 oz. Nomex Underwear
- C. 7 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
- D. 5 oz. Nomex Coveralls over Flameproof Cotton Coveralls
- E. Flameproof Cotton Coveralls over 7 oz. Nomex Underwear
- F. Aluminized Coat over Flameproof Cotton Coveralls
- G. Flameproof Cotton Coveralls over Cotton "T" Shirt

NOMEX TEST SERIES  
DEGREES - F  
THERMOCOUPLE NO. 5 - RIGHT SIDE

	<u>TEST NUMBER</u>							
<u>Time (Seconds)</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
0.0		+68°	+75°	+76°	+56°	+63°	+68°	+72°
0.5		79	84	87	61	70	68	83
1.0		93	100	96	67	78	68	83
1.5		98	116	99	68	79	68	88
2.0		100	125	102	69	79	68	98
2.5		101	127	104	71	79	68	98
3.0	NO THERMOCOUPLE	103	127	105	71	79	68	104
3.5		104	127	108	72	80	68	109
4.0		105	127	110	73	80	68	114
4.5		106	125	111	73	80	68	119
5.0		106	125	112	75	81	68	119
5.5		106	124	112	76	81	68	119
6.0		106	124	113	76	81	68	124
6.5		106	123	114	78	82	68	129
7.0		106	123	114	78	83	68	135
7.5		106	124	114	78	84	68	140
8.0		106	126	113	79	85	68	145
8.5		106	128		80	85	68	150
9.0		106	130		81	87	68	155
9.5		105	131		81	88	69	160
10.0		105	132		81	90	69	170
10.5		105	132		82	91	69	180
11.0		105	132		82	93	70	195
11.5		104	133		83	95	70	201
12.0		103	133		84	97	70	206
12.5		103	133		84	98	70	216
13.0		103	133		85	101	70	221
13.5		103	134		85	102	71	226
14.0		103	133		85	105	71	231

Material Over  
Thermocouple

A B C D E F G

Legend:

- A. 5 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
- B. 5 oz. Nomex Coveralls over 7 oz. Nomex Coveralls
- C. 7 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
- D. 5 oz. Nomex Coveralls over Flameproof Cotton Coveralls
- E. Flameproof Cotton Coveralls over 7 oz. Nomex Underwear
- F. Aluminized Coat over Flameproof Cotton Coveralls
- G. Flameproof Cotton Coveralls over Cotton "T" Shirt

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES  
DEGREES - F  
THERMOCOUPLE NO. 6 - RIGHT THIGH

<u>Time (Seconds)</u>	<u>TEST NUMBER</u>							
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
0.0	+101°	+64°	+79°	+75°	+67°	+67°	+86°	+78°
0.5	110	64	86	79	67	71	86	78
1.0	250	75	120	116	75	101	86	133
1.5	368	79	143	143	101	139	90	188
2.0	429	79	150	150	124	161	94	221
2.5	435	79	154	157	135	172	98	258
3.0	437	79	154	157	135	176	105	301
3.5		79	154	168	139	183	109	370
4.0		83	154	183	139	190	116	475
4.5		83	154	197	139	201	120	534
5.0		83	157	208	143	209	124	634
5.5		83	161	223	146	220	128	719
6.0		83	161	230	154	227	131	810
6.5		83	161	245	157	238	135	853
7.0		87	161	248	161	245	139	858
7.5		87	161	259	165	256	143	921
8.0		87	165	263	168	263	150	937
8.5		87	165	266	168	270	154	942
9.0		87	165	273	176	278	157	916
9.5		87	165	277	179	288	161	889
10.0		87	165	281	183	296	165	863
10.5		87	165	284	187	299	168	826
11.0		87	165	288	187	303	172	
11.5		90	165	288	190	306	172	
12.0		90	165	288	194	310	176	
12.5		90	165	288	198	310	179	
13.0		90	165	291	198	310	183	
13.5		90	165	291	198	310	183	
14.0		90	161	295	201	310	183	

Material Over  
Thermocouple

A B C D E F G H

Legend:

- A. 7 oz. Nomex Coveralls
- B. 5 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
- C. 5 oz. Nomex Coveralls over 7 oz. Nomex Underwear
- D. 7 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
- E. 5 oz. Nomex Coveralls over Flameproof Cotton Coveralls
- F. Flameproof Cotton Coveralls over 7 oz. Nomex Underwear
- G. Aluminized Coat over Flameproof Cotton Coveralls
- H. Flameproof Cotton Coveralls

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES  
DEGREES - F  
THERMOCOUPLE NO. 7 - RIGHT SIDE OF NECK

<u>Time (Seconds)</u>	<u>TEST NUMBER</u>							
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
0.0		+54°	+73°	+69°	+44°	+46°	+66°	+66°
0.5		72	80	93	78	73	101	114
1.0		271	129	159	149	95	167	170
1.5		291	141	187	150	97	344	196
2.0		290	145	195	151	95	398	186
2.5		283	144	198	151	95	392	186
3.0		276	143	198	152	95	377	186
3.5		266	141	200	153	95	356	186
4.0		256	140	202	149	93		176
4.5		249	140	204	145			170
5.0		244		203				165
5.5		235		202				
6.0		227						
6.5		219						
7.0		210						
7.5		202						
8.0		194						
8.5		187						
9.0		179						
9.5		174						
10.0		171						
10.5		166						
11.0		160						
11.5		154						
12.0		149						
12.5		145						
13.0		140						
13.5		137						
14.0		134						

FACE SHIELD COVERING THERMOCOUPLE  
DURING EACH TEST

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES  
DEGREES - F  
THERMOCOUPLE NO. 8 - RIGHT CHEST BETWEEN  
INNER AND OUTER GARMENT

<u>Time (Seconds)</u>	<u>TEST NUMBER</u>							
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
0.0	+105°	+79°	+76°	+72°	+64°	+63°	+74°	+66°
0.5	148	84	113	125	143	80	79	77
1.0	249	108	222	183	377	93	144	82
1.5	307	111	287	222		98	231	88
2.0	335	113	326	273		99	307	88
2.5	344	117	351	299		103	351	93
3.0	344	118	362	316		114	379	98
3.5		118	365	331		122	397	109
4.0		119	366	342		124	409	119
4.5		119	362	356		126	418	124
5.0		120	359	368		148	425	124
5.5		121	358	378		193	429	124
6.0		121		386		248	432	129
6.5		122		393		311	435	134
7.0		124		399		364	435	134
7.5		124		403		394	436	134
8.0		125		405		419	436	134
8.5		126		406		451	435	134
9.0		127		406		473	434	140
9.5		128		403		496	432	140
10.0		129		397		522		145
10.5		129				560		145
11.0		131						145
11.5		131						145
12.0		132						150
12.5		132						155
13.0		133						155
13.5		134						160
14.0		134						160

Material Over  
Thermocouple

A B B A B C D C

Legend:

- A. 7 oz. Nomex Coveralls
- B. 5 oz. Nomex Coveralls
- C. Flameproof Cotton Coveralls
- D. Aluminized Coat

NOTE: Data reduction stopped once peak temperature was reached.



NOMEX TEST SERIES  
DEGREES - F  
THERMOCOUPLE NO. 9 - RIGHT CHEST - OUTSIDE

<u>Time (Seconds)</u>	<u>TEST NUMBER</u>							
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
0.0	+80°	+75°	+68°	+68°	+47°	+55°	+81°	+76°
0.5	769	294	315	333	1815	121	535	313
1.0	1209	1174	1111	773	----	171	1165	484
1.5	1292	1183	1137	805	1660	171	1469	513
2.0	1301	1147	1067	858	1542	164	1502	529
2.5	1264	1084	991	844	1402	157	1438	544
3.0	1200	1009	921	854		146	1362	559
3.5		925	862	851		139	1273	589
4.0		862		844		132		609
4.5		808		826				629
5.0		751		787				644
5.5		709						659
6.0		677						675
6.5		648						690
7.0		624						705
7.5		585						715
8.0		563						715
8.5		549						725
9.0		531						740
9.5		513						745
10.0		496						765
10.5		478						776
11.0		460						786
11.5		439						791
12.0		429						811
12.5		411						826
13.0		393						836
13.5		380						861
14.0		365						866

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES  
DEGREES - F  
THERMOCOUPLE NO. 10 - RIGHT TEMPLE

<u>Time (Seconds)</u>	<u>TEST NUMBER</u>							
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
0.0	+72°	+55°	+73°	+64°	+54°	+64°	+67°	+61°
0.5	72	55	73	65	57	66	68	72
1.0	73	91	76	72	74	73	76	93
1.5	73	95	81	78	80	74	113	103
2.0	75	89	81	80	90	75	115	103
2.5	75	84	81	80	93	75	108	103
3.0	75	81	81	78	95	74	103	103
3.5		78	81	77	96	74	100	103
4.0		76	81	77	97	73		103
4.5		76	81	77	97			103
5.0		74	81	78	96			98
5.5		72	81		95			93
6.0		71	81		95			93
6.5		70	81		94			93
7.0		70	81					93
7.5		68	80					88
8.0		67	80					88
8.5		67						88
9.0		66						
9.5		65						
10.0		65						
10.5		65						
11.0		65						
11.5		64						
12.0		63						
12.5		63						
13.0		63						
13.5		63						
14.0		62						

FACE SHIELD COVERING THERMOCOUPLE  
DURING EACH TEST

NOTE: Data reduction stopped once peak temperature was reached.

NOMEX TEST SERIES  
DEGREES - F  
THERMOCOUPLE NO. 11 - RIGHT CHEST

Time (Seconds)	TEST NUMBER							
	1	2	3	4	5	6	7	8
0.0	NO THERMOCOUPLE	+87°	+87°	+82°	+74°	+76°	+79°	+71°
0.5		113	109	107	85	86	79	93
1.0		190	154	134	139	97	79	103
1.5		230	179	147	159	100	79	134
2.0		250	181	137	163	104	81	150
2.5		260	185	163	164	107	81	170
3.0		278	190	165	164	114	83	176
3.5		285	195	173	166	126	86	191
4.0		290	201	181	174	136	88	201
4.5		294	205	189	185	145	91	261
5.0		295	210	194	195	152	95	227
5.5		296	215	199	204	158	100	237
6.0		297	220	204	213	163	104	257
6.5		296	225	207	221	169	107	272
7.0		295	230	211	229	170	107	297
7.5		293	233	215	237	172	112	317
8.0		291	237	217	244	172	114	337
8.5		289	241	220	251	175	116	357
9.0		287	245	222	257	177	117	382
9.5		283	248	224	263	180	121	401
10.0		280	252	227	268	189	123	421
10.5		276	255	228	274	199	124	446
11.0		273	258	229	278	209	126	465
11.5		269	261	229	282	222	128	485
12.0		264	261	230	286	231	129	510
12.5		260	264	230	289	241	131	525
13.0		255	264	230	293	251	133	545
13.5		251	265	230	297	262	133	565
14.0		245	265	230	301	272	135	575

Material Over  
Thermocouple

A B C D E F G

Legend:

- A. 5 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
- B. 5 oz. Nomex Coveralls over 7 oz. Nomex Underwear
- C. 7 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
- D. 5 oz. Nomex Coveralls over Flameproof Cotton Coveralls
- E. Flameproof Cotton Coveralls over 7 oz. Nomex Underwear
- F. Aluminized Coat over Flameproof Cotton Coveralls
- G. Flameproof Cotton Coveralls over Cotton "T" Shirt

NOMEX TEST SERIES  
DEGREES - F  
THERMOCOUPLE NO. 12 - RIGHT THIGH

	<u>TEST NUMBER</u>							
<u>Time (Seconds)</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
0.0		+81°	+89°	+85°	+75°	+70°	+89°	+81°
0.5		93	96	93	79	74	89	91
1.0		161	151	137	98	98	90	176
1.5		206	163	147	117	102	92	233
2.0		223	167	153	129	103	98	320
2.5		239	169	158	137	109	107	426
3.0		249	170	161	142	113	116	522
3.5		256	171	165	145	120	124	614
4.0		261	172	167	148	125	131	649
4.5	NO THERMOCOUPLE	264	174	171	150	131	139	675
5.0		266	176	173	153	137	144	690
5.5		268	178	176	157	142	150	700
6.0		270	179	178	161	146	154	705
6.5		270	180	181	165	149	158	715
7.0		270	182	184	170	153	161	741
7.5		270	182	186	174	157	166	746
8.0		270	183	188	179	160	169	751
8.5		273	184	190	183	162	173	751
9.0		279	185	193	188	164	176	746
9.5		285	185	195	190	165	181	741
10.0		291	186	197	193	165	186	741
10.5		294	186	199	197	165	191	730
11.0		294	186	201	199	165	194	720
11.5		291	186	201	201	165	197	705
12.0		288	185	203	202	163	201	695
12.5		284	185	204	204	162	205	685
13.0		279	184	204	205	161	207	664
13.5		275	184	206	207	160	210	659
14.0		270	183	208	207	159	212	639

Material Over  
Thermocouple

A B C D E F G

Legend:

- A. 5 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
- B. 5 oz. Nomex Coveralls over 7 oz. Nomex Underwear
- C. 7 oz. Nomex Coveralls over 4.3 oz. Nomex Underwear
- D. 5 oz. Nomex Coveralls over Flameproof Cotton Coveralls
- E. Flameproof Cotton Coveralls over 7 oz. Nomex Underwear
- F. Aluminized Coat over Flameproof Cotton Coveralls
- G. Flameproof Cotton Coveralls